

On the nature of the $\pi_2(1880)$

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Abstract

The strong decays of the $\pi_2(1880)$ as the 2^1D_2 quark-antiquark state are investigated in the 3P_0 model and the flux-tube model, respectively. The results are similar in the two models. It is found that the decay patterns of the conventional 2^1D_2 meson and the 2^{-+} light hybrid are very different, and the experimental evidence for the $\pi_2(1880)$ is consistent with it being the conventional 2^1D_2 meson rather than the 2^{-+} light hybrid. The possibility of the $\pi_2(1880)$ being a mixture of the conventional $q\bar{q}$ and the hybrid is discussed.

Key words: mesons, 3P_0 model, flux-tube model, decays

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I. Introduction

Experimentally, the ACCMOR Collaboration in 1981 observed a $I = 1$, $J^{PC} = 2^{-+}$ structure at 1850 MeV in the $f_2(1270)\pi$ D -wave with a width of about 240 MeV[1]. Subsequently, the VES Collaboration reported a $J^{PC} = 2^{-+}$ threshold enhancement in the $a_2(1320)\eta$ channel with a mass of about 1840 MeV and width of about 210 MeV in their $\eta\eta\pi^-$ data[2] and also in $\eta\pi^+\pi^-\pi^0$ data where $a_2(1320) \rightarrow \pi^+\pi^-\pi^0$; they also observed a strong peak at the same mass in the $f_2(1270)\pi$ D -wave in their 4π data[3]. In 2001, Anisovich et al. reported a $I = 1$, $J^{PC} = 2^{-+}$ resonance with a mass of about 1880 MeV and a width of about 255 MeV in the $a_2(1320)\eta$ and $f_2(1270)\pi$ D -wave[4, 5]. More recently, a similar 2^{-+} resonance was observed by the E852 Collaboration in the $f_1(1285)\pi$ [6], $\rho\omega$ [7], and $a_2(1320)\eta$ [8] channels, respectively. It has been established that these observations in different channels refer to a single state $\pi_2(1880)$ [9, 10]. In the Meson Summary Table of the PDG2008, the mass and width of the $\pi_2(1880)$ are quoted to be 1895 ± 16 MeV and 235 ± 34 MeV, respectively[10].

As for the $\pi_2(1880)$ nature, after a 2^{-+} hybrid conjecture [$\pi_2(H)$] was first proposed by Anisovich et al.[4], several groups also claimed the $\pi_2(1880)$ being a viable non-exotic hybrid candidate[5, 6, 7, 8, 9, 11]. With the $\pi_2(1670)$ as the well-established 1^1D_2 $q\bar{q}$ state[10], the $\pi_2(1880)$ looks like the $\pi_2(H)$ rather than the 2^1D_2 isovector $q\bar{q}$ state [$\pi_2(2D)$] based on its mass, because the observed mass of the $\pi_2(1880)$ just overlaps the flux-tube model prediction of about $1.8 \sim 1.9$ GeV for the light 2^{-+} hybrid[12], but is about 200 MeV lower than the Godfrey-Isgur (GI) quark model prediction of about 2.1 GeV for the 2^1D_2 nonstrange $q\bar{q}$ state[13]. However, comparing the experimental evidence for the $\pi_2(1880)$ with the strong decay properties of the $\pi_2(H)$ expected by the model of hybrid meson decay developed by Page, Swanson, and Szczepaniak(PSS) based on the heavy quark expansion of QCD and the strong coupling flux tube picture of nonperturbative glue[14](see the Table II of Ref.[14]), one can find the following features of the $\pi_2(1880)$ casting doubt over the hybrid interpretation for the $\pi_2(1880)$:

- i) The observation in the $\rho\omega$ channel of the $\pi_2(1880)$ is inconsistent with the hybrid interpretation where the coupling of the $\pi_2(H)$ to $\rho\omega$ is expected to vanish.
- ii) The observation in the $f_2(1270)\pi$ D -wave of the $\pi_2(1880)$ is also inconsistent with the

hybrid interpretation where the $f_2(1270)\pi$ D -wave is strongly suppressed and the S -wave is dominant.

iii) The measured width of the $\pi_2(1880)$, 235 ± 34 MeV, is again inconsistent with the hybrid interpretation where the $\pi_2(H)$ width is less than 100 MeV.

Therefore, the claims for the $\pi_2(1880)$ can be accepted as a resonance state of exotic nature may be premature. In fact, it is important to exhaust possible conventional $q\bar{q}$ description of the $\pi_2(1880)$ before resorting to more exotic interpretation such as a hybrid. In this work, we shall discuss the possibility of the $\pi_2(1880)$ being the $\pi_2(2D)$. As mentioned above, a problem with identifying the $\pi_2(1880)$ with the $\pi_2(2D)$ is that its mass is about 200 MeV lower than the expectation from the GI quark model. Notice that the $a_1(1700)$ and $a_2(1700)$, both about 100-200 MeV lower in mass than the GI quark model anticipated[13], turn out the excellent candidates for radial excitations[14, 15], which indicates that GI quark model maybe overestimate the masses of the higher- L radially excited mesons by about 100-200 MeV, and therefore the $\pi_2(2D)$ with a mass about 1.9 GeV is not implausible. Also, the mass of the $\pi_2(2D)$ in the spectrum integral equation[16] is expected to be about 1.937 GeV, very close to the $\pi_2(1880)$ mass. Therefore, the assignment of the $\pi_2(1880)$ as the $\pi_2(2D)$ seems also possible based on its mass. However, only the $\pi_2(1880)$ mass information is insufficient to identify its nature, further studies of its decay dynamics are needed. The main purpose of this work is to discuss whether the $\pi_2(2D)$ interpretation for the $\pi_2(1880)$ is reasonable or not by investigating its strong decay properties in two models, the 3P_0 model and the flux-tube model.

The organization of this paper is as follows. In Sec. II, the decay properties of the $\pi_2(1880)$ as the $\pi_2(2D)$ within the 3P_0 model and the flux-tube model are presented. The discussions are presented in Sec. III, and the summary and conclusion are given in Secs. IV.

II. Decay properties of the $\pi_2(1880)$ as the $\pi_2(2D)$

The 3P_0 model and the flux-tube model which are the standard models for strong decays at least for mesons in the initial state, have been widely used to evaluate the strong decays of hadrons[15, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27], since they give a good description of many of the observed decay amplitudes and partial widths of the hadrons. In this work, we

shall employ the 3P_0 model and the flux-tube model with simple harmonic oscillator (SHO) wave functions¹ to evaluate the two-body open-flavor strong decay widths of the initial state. Since there exists exhaustive literature on these two models, we just list the numerical values of the partial decay widths of the $\pi_2(1880)$ as the $\pi_2(2D)$ in Table 1. In our calculation, the SHO wave function scale parameter β , the pair production strength parameter γ in the 3P_0 model, the pair-creation constant γ_0 and the string tension b in the flux-tube model, and the constituent quark mass m_q are² $\beta_A = \beta_B = \beta_C = \beta = 0.4$ GeV, $\gamma = 8.77$, $\gamma_0 = 14.3$, $b = 0.18$ GeV², $m_u = m_d = 0.33$ GeV, and $m_s = 0.55$ GeV[20, 26], respectively. The meson masses used to determine the phase space and final state momenta are³ $M_\pi = 138$ MeV, $M_K = 496$ MeV, $M_\eta = 548$ MeV, $M_\rho = 776$ MeV, $M_{K^*} = 894$ MeV, $M_\omega = 783$ MeV, $M_{a_1(1230)} = 1230$ MeV, $M_{f_1(1285)} = 1282$ MeV, $M_{a_2(1320)} = 1318$ MeV, $M_{f_2(1270)} = 1275$ MeV, $M_{f_0(1370)} = 1370$ MeV, $M_{\rho(1450)} = 1465$ MeV, and $M_{K_1(1270)} = 1272$ MeV.

It is clear from Table 1 that the numerical results in the 3P_0 model are similar to those in the flux-tube model. Very characteristic differences between the $\pi_2(2D)$ and $\pi_2(H)$ assignments for the $\pi_2(1880)$ are evident when we compare our results with the expectations from the PSS model for the $\pi_2(H)$ [14]. The total width of the $\pi_2(2D)$ is expected to be about 223 MeV in the 3P_0 model or about 233 MeV in the flux-tube model, both in good agreement with the $\pi_2(1880)$ width; however, the total width of the $\pi_2(H)$ is expected to be less than 100 MeV, at least 100 MeV lower than the experiment. The partial width of the $\pi_2(2D) \rightarrow \rho\omega$ is significantly large, consistent with the observation in the $\rho\omega$ channel of the $\pi_2(1880)$; whereas the $\pi_2(H) \rightarrow \rho\omega$ is expected to vanish. The $\pi_2(2D) \rightarrow f_2(1270)\pi$ is dominant in the D -wave and the D -wave width is significantly large, and therefore the $\pi_2(2D)$ should be readily observable in the $f_2(1270)\pi$ D -wave, consistent with the observation of the $\pi_2(1880)$ in the $f_2(1270)\pi$ D -wave; while the $\pi_2(H) \rightarrow f_2(1270)\pi$ is strongly suppressed in the D -wave and dominant in the S -wave. Also, for the $\pi_2(2D)$, the partial width of the K^*K^* mode, the F -wave widths of the $\rho\pi$, K^*K , K^*K^*

¹This is typical of decay calculations and it has been demonstrated that using the more realistic wave functions, such as those obtained from Coulomb, plus the linear potential model, does not change the results significantly[21, 22, 23].

²Our value of γ is higher than that used by Ref.[26] (0.505) by a factor of $\sqrt{96\pi}$ due to different field conventions, constant factor in T , etc. The calculated results of the widths are, of course, unaffected.

³We assume that the $f_0(1370)$ is the ground scalar meson as Refs.[15, 24, 25].

Table 1: Decays of the $\pi_2(1880)$ as the $\pi_2(2D)$ in the 3P_0 model and the flux-tube model. The initial state mass is set to 1895 MeV.

Mode	Γ_{LS} in 3P_0 model (MeV)	Γ_{LS} in flux-tube model (MeV)
$\rho\pi$	$\Gamma_{P1} = 5.58$	$\Gamma_{P1} = 6.07$
	$\Gamma_{F1} = 66.04$	$\Gamma_{F1} = 71.92$
K^*K	$\Gamma_{P1} = 14.46$	$\Gamma_{P1} = 15.75$
	$\Gamma_{F1} = 5.76$	$\Gamma_{F1} = 6.27$
$\rho\omega$	$\Gamma_{P1} = 29.24$	$\Gamma_{P1} = 31.84$
	$\Gamma_{F1} = 10.19$	$\Gamma_{F1} = 11.10$
K^*K^*	$\Gamma_{P1} = 5.25$	$\Gamma_{P1} = 5.71$
	$\Gamma_{F1} = 0.06$	$\Gamma_{F1} = 0.07$
$\rho(1450)\pi$	$\Gamma_{P1} = 19.15$	$\Gamma_{P1} = 11.82$
	$\Gamma_{F1} = 1.48$	$\Gamma_{F1} = 1.09$
$f_0(1370)\pi$	$\Gamma_{D0} = 4.20$	$\Gamma_{D0} = 4.57$
$f_1(1285)\pi$	$\Gamma_{D1} = 5.29$	$\Gamma_{D1} = 5.76$
$a_1(1260)\eta$	$\Gamma_{D1} = 0.36$	$\Gamma_{D1} = 0.40$
$K_1(1270)K$	$\Gamma_{D1} = 0.25$	$\Gamma_{D1} = 0.27$
$a_2(1320)\eta$	$\Gamma_{S2} = 20.86$	$\Gamma_{S2} = 22.71$
	$\Gamma_{D2} = 0.05$	$\Gamma_{D2} = 0.06$
	$\Gamma_{G2} = 0.00$	$\Gamma_{G2} = 0.00$
$f_2(1270)\pi$	$\Gamma_{S2} = 11.82$	$\Gamma_{S2} = 12.88$
	$\Gamma_{D2} = 22.58$	$\Gamma_{D2} = 24.59$
	$\Gamma_{G2} = 0.57$	$\Gamma_{G2} = 0.62$
Γ	223.19	233.50

and $\rho(1450)\pi$ modes, and the G -wave width of the $f_2(1270)\pi$ mode are not zero, especially the $\rho\pi$ F -wave width is significantly large; whereas for the $\pi_2(H)$, all these widths vanish exactly. The further experimental study on these decay modes are also important to examine whether the $\pi_2(1880)$ is the $\pi_2(2D)$ or the $\pi_2(H)$.

From these remarkable discriminants between the $\pi_2(2D)$ and the $\pi_2(H)$, it is clear that the available experimental evidence for the $\pi_2(1880)$ is consistent with it being the $\pi_2(2D)$ rather than the $\pi_2(H)$ ⁴, assuming the 3P_0 model and the flux-tube model are accurate.

⁴The one exception to this is that our predicted $\Gamma(a_2(1320)\eta)/\Gamma(f_1(1285)\pi)$ for the $\pi_2(2D)$ is about 4, inconsistent with the measured value of 22.7 ± 7.3 [6] which agrees with the PSS model prediction of about 23 for the $\pi_2(2H)$ [14]. Notice that the systematic error is not estimated in this measured datum, and this datum is not used for averages, fits, limits, etc. by PDG2008[10]. The further confirmation of this ratio is needed.

In order to test the robustness of our results, the dependence of the predicted results on the initial state mass M_A and the SHO function scale parameter β is studied. We show the variation of the total width of the $\pi_2(2D)$ with M_A and β in Fig. 1. In both the 3P_0 model and the flux-tube model, the total width of the $\pi_2(2D)$ becomes large with the increase of the M_A , and it always lies in the width range of the $\pi_2(1880)$. When the β varies from 300 to 500 MeV, in the flux-tube model the $\pi_2(2D)$ width varies from about 230 to 260 MeV, depending weakly on the β , while in the 3P_0 model it varies dramatically with the β . In order to reproduce the $\pi_2(1880)$ width in the 3P_0 model, it requires $\beta \simeq 370 \sim 420$ MeV, overlapping the typical value of about $350 \sim 450$ MeV used in the computation of the light meson decays for the SHO wave functions with a common β [23, 24].

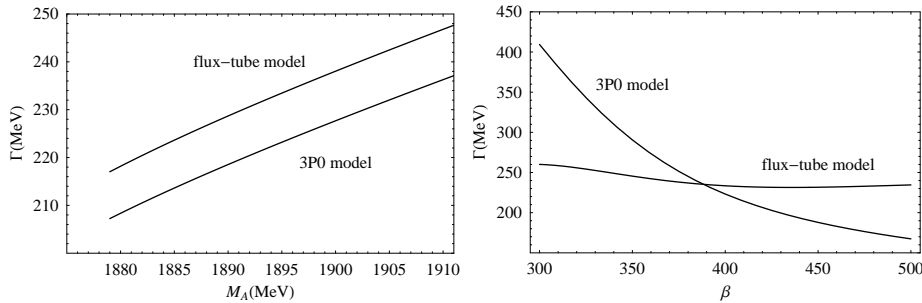


Figure 1: The total width of the $\pi_2(2D)$ dependence on the M_A and β in the 3P_0 model and the flux-tube model.

The partial widths of the $\pi_2(2D)$ versus the M_A are shown in Fig. 2, where the variations of the partial widths of the $\pi_2(2D)$ with the M_A in the 3P_0 model are similar to those in the flux-tube model. The partial widths increase when the M_A increases and the dominant decay modes are $\rho\pi$, $\rho\omega$, $f_2(1270)\pi$, KK^* , $\rho(1450)\pi$ and $a_2(1320)\eta$.

The partial widths of the $\pi_2(2D)$ versus the β are shown in Fig. 3. We see from Fig. 3 that in two models, $\rho\pi$, $\rho\omega$, $f_2(1270)\pi$, KK^* , $\rho(1450)\pi$ and $a_2(1320)\eta$ are still the dominant decay modes when the β varies. For small β ($\beta \simeq 300 \sim 350$ MeV), KK^* dominates $a_2(1320)\eta$, however for large β ($\beta \simeq 450 \sim 500$ MeV), $a_2(1320)\eta$ dominates KK^* . In the vicinity of $\beta = 400$ MeV, $\Gamma(KK^*) \simeq \Gamma(a_2(1320)\eta)$. The similar behavior also exists for the modes $f_1(1285)\pi$ and K^*K^* . The measurement of the $\Gamma(KK^*)/\Gamma(a_2(1320)\eta)$ and $\Gamma(f_1(1280)\pi)/\Gamma(K^*K^*)$ for the $\pi_2(1880)$ would be useful for the reasonable choice for the β .

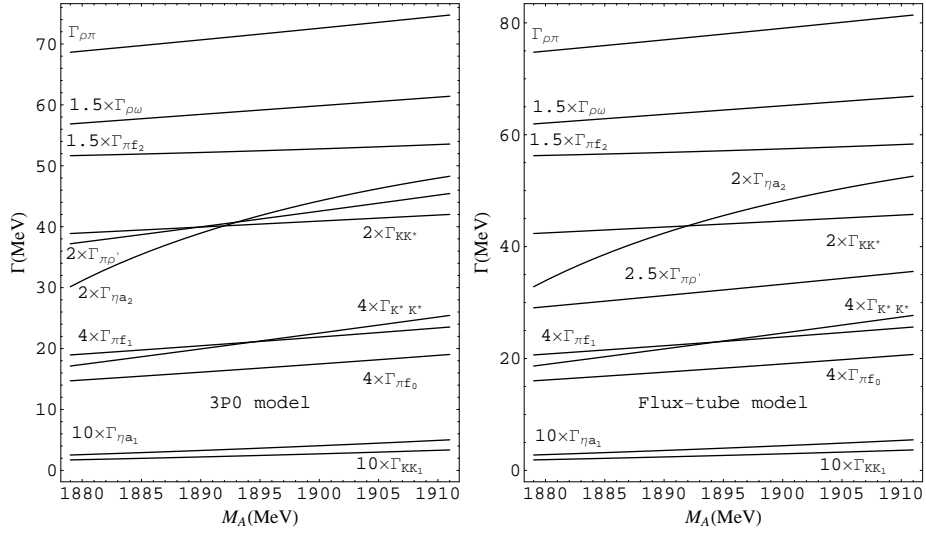


Figure 2: The partial widths of the $\pi_2(2D)$ dependence on the M_A in the 3P_0 model and the flux-tube model. ρ' denotes the $\rho(1450)$.

We note that for the $\pi_2(2D)$, the $f_2(1270)\pi$ D -wave dominates the S -wave and the $\rho\pi$ F -wave dominates the P -wave, which is unusual because in most cases the lower partial waves are dominant. As mentioned above, these results are remarkably different with the expectations from the PSS model[14] for the $\pi_2(H)$. We find that in both the 3P_0 model and the flux-tube model, the F -wave always dominates the P -wave for the $\pi_2(2D) \rightarrow \rho\pi$ and the D -wave always dominates the S -wave for the $\pi_2(2D) \rightarrow f_2(1270)\pi$ when the M_A varies in the mass range of the $\pi_2(1880)$ and β varies in the range 370-420 MeV, the required range for reproducing the $\pi_2(1880)$ width in the 3P_0 model mentioned above. Determining these partial widths ratios experimentally is very important to distinguish the $\pi_2(2D)$ interpretation from the $\pi_2(H)$ assignment for the $\pi_2(1880)$.

III. Discussions

Generally speaking, the pure $\pi_2(2D)$ can mix with the pure $\pi_2(H)$ to produce the physical state $\pi_2(1880)$. The available experimental evidence for the $\pi_2(1880)$ is in favor of the $\pi_2(2D)$ interpretation for the $\pi_2(1880)$ based on the remarkably different decay patterns of the $\pi_2(2D)$ and $\pi_2(H)$, but it is insufficient to quantitatively determine the $q\bar{q}$ -hybrid content of the

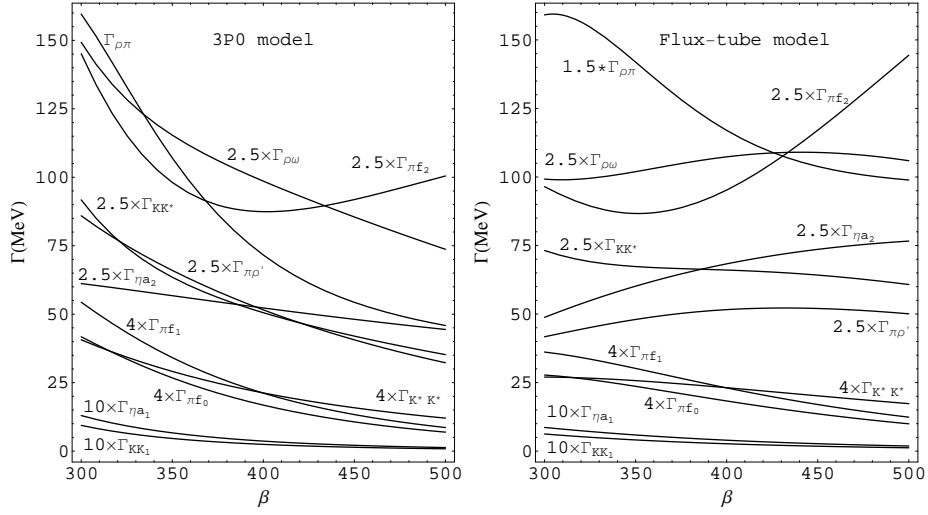


Figure 3: The partial widths of the $\pi_2(2D)$ dependence on the β in the 3P_0 model and the flux-tube model. ρ' denotes the $\rho(1450)$.

$\pi_2(1880)^5$, which is essential to confirm or refute that the possibility of the hybrid admixture in the $\pi_2(1880)$. Therefore, the possibility of the $\pi_2(1880)$ being in fact a mixture of the $\pi_2(2D)$ and $\pi_2(H)$ might exist at present time.

We can qualitatively estimate the hybrid component of the $\pi_2(1880)$ would be small based on its available experimental information. The $\pi_2(H) \rightarrow \rho\omega$ is expected to vanish from the PSS model[14], therefore, the observation of the $\pi_2(1880)$ in the $\rho\omega$ channel[7] makes that the substantial hybrid admixture in the $\pi_2(1880)$ seems impossible. However, it should be noted that the $\pi_2(1880)$ signal in the $\rho\omega$ channel was observed only by the E852 Collaboration[7], and even it is not clear whether the unitarity conserving fit to the $\rho\omega$ mass distributions would need to have the $\pi_2(1880)$ decaying to $\rho\omega$ or not⁶. Therefore, further evidence is needed to confirm whether the hybrid component of the $\pi_2(1880)$ is small or not. Fortunately, as mentioned in Sec. I, the $\pi_2(1880)$ has been observed by three different groups in the $f_2(1270)\pi$ D -wave, which implies that the $\pi_2(H)$ component of the $\pi_2(1880)$ would be small because the $\pi_2(H) \rightarrow f_2(1270)\pi$ is strongly suppressed in the D -wave. Similarly, the further experimental information of the $\pi_2(1880)$ in the K^*K^* and $[\rho\pi]_{L=3}$ channels would be useful to shed light on this issue.

⁵Within the $\pi_2(1880)$ being the mixture of the $\pi_2(2D)$ and $\pi_2(H)$, the measured partial widths of the $\pi_2(1880)$ are needed to determine the hybrid-quarkonium content of the $\pi_2(1880)$ quantitatively.

⁶We thank the anonymous referee for pointing out this matter.

Finally, our predicted $\Gamma(a_2(1320)\eta)/\Gamma(f_1(1285)\pi)$ for the $\pi_2(2D)$ inconsistent with the measurement of the E852 Collaboration[6] may be a hint for the $\pi_2(1880)$ being in fact a mixture of the $\pi_2(2D)$ and $\pi_2(H)$, and the small hybrid admixture in the $\pi_2(1880)$ might make this measured ratio shift from the predicted value for the pure $\pi_2(2D)$.

IV. Summary and conclusion

The strong decays of the $\pi_2(1880)$ as the $\pi_2(2D)$ are investigated in both the 3P_0 model and the flux-tube model. The overall behaviors of the decay modes in the 3P_0 model are similar to those in the flux-tube model. The decay properties of the $\pi_2(2D)$ and the $\pi_2(H)$ are remarkably different. The decay modes $\rho\pi$, $\rho\omega$, $f_2(1270)\pi$, K^*K , K^*K^* and $\rho(1450)\pi$ are crucial for distinguishing the conventional quarkonium interpretation from the hybrid assignment of the $\pi_2(1880)$. The available experimental evidence for the $\pi_2(1880)$ is consistent with it being the conventional 2^1D_2 $q\bar{q}$ meson rather than the light 2^{-+} hybrid. The possibility of the small hybrid admixture in the $\pi_2(1880)$ might exist. Further experimental study on the partial widths of the $\pi_2(1880)$ is desirable. We tend to conclude that the $\pi_2(1880)$ is the convincing 2^1D_2 $q\bar{q}$ state or the 2^1D_2 $q\bar{q}$ with small hybrid admixture.

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